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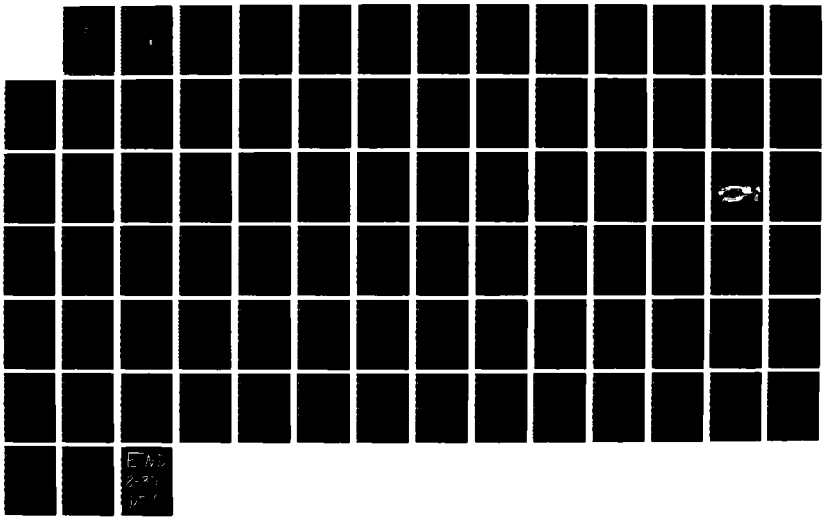

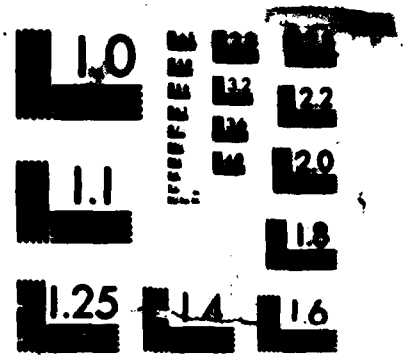

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OVERVIEW OF PAVEMENT MANAGEMENT

BY

FRANCIS P. CASTALDO

Contract No. N00228-85-G-3323

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A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

SUMMER 1987

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BY

FRANCIS P. CASTALDO

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ABSTRACT

Government agencies need an efficient pavement management program today to achieve the best road value for the available funds. This report defines five basic functions of pavement management and discusses current efficient management practices within each pavement management function. Major cost factors associated with pavement management are discussed to illustrate some of the factors that should be examined when trying to improve efficiency. Pavement design is discussed to illustrate the various factors which effect pavement design. An overview of several current pavement design methods show which factors are or are not accounted for when using the different design methods.

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CHAPTER I
INTRODUCTION

1.1 Purpose

The purpose of this report is to give the new engineer a basic overview of the different steps involved with pavement management, and a starting point from which to build on. Pavement management with respect to cost is also covered to illustrate some of the factors that should be examined in order to get more pavement for the money. The idea of the Pavement Management System is discussed because it is the best way to approach pavement management.

1.2 History

Since the invention of the wheel, man has built roads for transportation. One of the oldest roads of which there are traces today is on the island of Crete, this road, which was surfaced with stone, probably was constructed before 1500 B.C..

The Roman Empire constructed a vast road system of roads from approximately 400 B.C. to A.D.200. The roads generally consisted of several layers of stone, 3 to 5 feet thick in some instances. This was the basic road building techniques until the 19th century.[1]

The first modern road building techniques appeared in the 19th century. Tresquet of France developed many methods of road construction and Macadam of England developed a method of road construction using broken stones. His name is still associated today with this method.

Early highways in the U.S. were constructed with many different materials including: cobblestones, wood blocks, logs, gavel, and other materials. The first brick pavement was constructed in Charleston, West Virginia, in 1871, and sheet asphalt was first used in 1879 on Pennsylvania Avenue in Washington D.C.. Bellefontaine, Ohio, is credited with having the first street pavement of Portland-cement concrete. Wayne County, Michigan, constructed the first 2 rural road of concrete in 1909.

With the introduction of the automobile, travel speed was increased. Road roughness then became a high concern. In addition, the automobile contributed to a higher rate of deterioration of pavements. The automobile changed the way of American life. Because of the speed of operation and economy, better highway development became a necessity.

1.3 Types of Pavement

Types of pavement can be placed into two basic categories; flexible pavements and rigid pavements. The pavement structure itself includes all components above the subgrade. A flexible pavement usually consists of a thin wearing or surface course, a base course, and a subbase course, that are all placed over a compacted subgrade. A rigid pavement is composed of Portland-cement concrete which may or may not have a base course between the pavement and the subgrade. The two general types of pavements are classified by the way the traffic loads are distributed to the subgrade. Rigid pavement distribute loads over a wide

area of subgrade so the slab itself carries a major portion of the load. Flexible pavements are built in layers with successive higher quality materials which will distribute the load over the subgrade.

1.3.1 Flexible Pavements

The majority of flexible pavements are constructed with asphalt concrete. The surface course or more of the layers may be of asphalt concrete. A full depth asphalt pavement is one which all the layers over the subgrade or improved subgrade are constructed with asphalt concrete. A deep strength flexible pavement is referred to when the base layer in addition to the surface layer are constructed with asphalt concrete.

Other types of flexible pavements that will not be discussed in detail are:

Unsurfaced Roads - some rural roads consist of natural earth with little or no improvement. Maintenance consists mainly of occasional grading and repairing soft spots with earth or gravel.

Untreated Surfaces - these roads consist of aggregate placed over an untreated or compacted subgrade.

Brick or Stone Roads - bricks or stone are placed on beddings of different materials and over an aggregate base or subbase.[3]

1.3.2 Rigid Pavements

Rigid pavements can be classified into three types depending on the reinforcement used within the concrete. They are; unreinforced concrete pavement, simple reinforced

concrete pavement, and continuous reinforced concrete pavement.

The majority of concrete pavement uses reinforcing steel to limit crack openings which provides for better load transfer by grain or aggregate interlock. Cracks will occur because of contraction or warping of the concrete pavement. Joints are designed to limit these cracks. Load transfer devices are used to limit the destructive effect caused by heavy wheel loads crossing over pavement joints. Load transfer can be accomplished by using dowel bars, constructing slabs with thickened edges, or using a concrete treated base course.

Unreinforced Concrete pavement usually consists of short slabs (15-20 feet or less) which limits cracking. Simple reinforced concrete pavement includes tie bars which hold the joints together. Continuous reinforced concrete pavement is constructed with limited joints and adequate steel to carry the load when the concrete cracks.

1.3.3 Composite Pavements

A composite pavement is a combination of a flexible pavement and rigid pavement. Generally pavements are not designed like this, but are a result of stage construction or resurfacing operations. The vast majority of this type pavement consists of an asphalt overlay over an existing concrete pavement or cement treated base. A composite pavement of this type is a rigid pavement, but the surface has many flexible characteristics. A composite pavement may

be treated as a flexible or rigid pavement, depending on the structure.

1.4 Water Effects

Regardless of the type of pavement, water is the most significant cause of damage to pavement and the underlying support section. Both rainfall and climate conditions can be the most important factors effecting pavement performance. Rainfall attributes to higher moisture contents of the subgrade, which reduces the subgrade strength and thus the load carrying capacity of the pavement. Frost action includes frost heave and loss of subgrade support during the frost melt period or spring thaw. Frost heave occurs when ice lenses form in frost susceptible soils which can raise a portion of the pavement. The best way to guard against water induced damage is to simply get rid of the water and keep it out.[4]

Proper drainage is a necessity to guide water away from the pavement structure. Drainage can be in the form of slope control (road crowns and side slopes), ditches, culverts, storm drains, sub-surface drains, etc...Pavement design with the selection of proper materials will also limit pavement failure due to water.

1.5 Pavement Management

What is pavement management? Pavement management can be defined as directing the various activities that deal with providing and maintaining pavements in a safe and usable condition for the users. Pavement management can further be broken down into two levels, the network level

and the project level. Pavement management at the project level deals with the technical and detailed information related to a specific pavement section. It involves the lower management levels. The American Association of State Highway and Transportation Officials(AASHTO) lists several examples of project level pavement management:

- Establishing priorities for maintenance, rehabilitation, and reconstruction based on criteria set by top management.

- Obtaining feedback relative to pavement performance to provide input into pavement design, construction, and maintenance activities.

- Applying benefit/cost analysis when considering alternatives.

- Considering all design parameters such as foundation strength, number of projected axle loads, materials specifications, climate, etc., when designing a pavement structure.[5]

Pavement management at the network level deals with summary information related to the entire highway network. It involves policy and programming decisions by upper level management.[6] Examples of network level management are:

- Set policy.

- Establish rehabilitation programs.

- Justify budget requests.

The emphasis of current pavement management practice is concerned mostly with the maintenance of existing pavements

rather than new construction. Table 1.1 shows that the miles of new road constructed has slowed considerably since 1920.

YEAR	MILES OF ROAD
1900	2.5 MILLION
1920	3.5 MILLION
1987	3.9 MILLION

Table 1.1

In order for a pavement management program to be efficient and effective, the building and maintaining of pavements should be done at the lowest cost. The need for an effective pavement management program on the local or state level is a must. It simply costs too much money not to have one.

Roads are responsible for our current standard of living. Highway transportation is a huge business, with an economic impact on every American. For example, in 1984, highway passenger and freight transportation were responsible for nearly 16% of the America's Gross National Product. Past and current trends show that as the economy expands, dependence on highway mobility increases. People expect good roads as they affect every aspect of their lives and safety is imperative.

Most user costs are increased greatly with bad roads. Inefficient operator speeds caused by slowdowns, stops, and starts, effect travel time and user comfort. Studies from the Transportation Research Board have shown that fuel consumption can increase by 25% while driving on bad roads.

Additionally, vehicle life can be shortened by almost 10%. These costs not only effect individual users, but the general public as well. Emergency vehicles, school buses, and transit buses all experience the same decrease in efficiency as the private vehicle and tax dollars pay for them.[7]

Highways need to be effective to safely get the users where they want to go. Pavement management is needed to get the most road for your dollar.

1.5.1 Functions of Pavement Management

Many factors or activities need to be examined for the proper management of pavements. Some examples include: planning, research, design, construction, rehabilitation, maintenance, budgeting, programming, type selection, and monitoring. The best way to implement a pavement management program is to take a systemic approach in order to coordinate and direct all activities toward achieving the best value possible for the available funds in providing safe and economical roads.

There are five basic functions of pavement management. They are:

1. Monitoring the Pavement Condition.
2. Inventory and Organizing Pavement Data
3. Analyzing Pavement Data.
4. Decision of Alternatives.
5. Implementation of Decisions.[8]

CHAPTER 2
MONITORING THE PAVEMENT CONDITION

2.1 Monitoring

The monitoring function of pavement management is very important. The condition surveys, and the structural evaluations are what all future considerations or maintenance strategies are based on. The monitoring of the pavement condition is completed to examine the condition of the assets in order to identify if or when maintenance needs to be done.

There are four basic different pavement properties or conditions that need to be evaluated and monitored. They are:

1. Pavement Performance
2. Pavement Condition
3. Structural Capacity
4. Skid Resistance

2.2 Pavement Serviceability and Performance

Pavement performance evaluations involve the functional performance of a pavement in its entirety. Units of measure include the riding quality or serviceability and the associated traffic. One example of the pavement performance measurement is the Present Serviceability Index , developed by Carey and Irick. It was first used in conjunction with the American Association of State Highway Officials (AASHO) Road Test. AASHO was later changed to AASHTO when Transportation was added. AASHTO will be used throughout this report. The serviceability measure simulates the users

opinions and is based primarily on road roughness.

2.3 Serviceability

Serviceability is defined as a measure of riding quality of a certain road section at a particular point in time. It is a subjective rating of the riding quality according to roughness. Roughness can be defined as the surface characteristics of a pavement which affect vehicle operating costs and the riding quality of the pavement as perceived by the user. Because it is bias to personal opinion, roughness or serviceability can be hard to measure. Specifically, it depends on the user. the vehicle, and the pavement. The Present Serviceability Index can be measured by both mechanical means or by a panel of individuals.

2.3.1 Present Serviceability Rating

Panel rating measurements of the Serviceability Index are referred to as Present Serviceability Ratings (PSR). Errors do occur with this rating method because of individual error. Individuals may consistently rate high, median, or low. Additionally, an individual may distort a particular rating because of impressions or opinions. To reduce this error or to increase rating accuracy, a panel of individuals, vice one individual, should complete the PSR . The more ratings or individuals performing the ratings, the more accurate the results should be. Typically four to five individual raters make up a satisfactory panel, but it depends on the permissible error. The PSR is performed by having the panel ride over a pavement section and recording

their individual subjective opinion on a form. The form allows rating the section on a scale from zero to five, with zero being a very poor pavement section and five being a very good pavement section with respect to riding comfort. The PSR[10] is found by averaging all the individual rating numbers. Figure 2.1 shows an example of a form like the one used at the AASHTO Road Test.

Evaluation Form For PSR

```
                                  5 -
                                    ¶ Very Good
      Acceptable?                 4 -
                                    ¶ Good
Yes          ¶___¶                3 -
             ¶---¶                  ¶ Fair
No           ¶   ¶                2 -
             ¶---¶                  ¶ Poor
Undecided    ¶___¶                1 -
                                    ¶ Very Poor
                                  0 -
```

Section Identification.....Rating

Rater..... Date..... Time.....

Vehicle.....

Figure 2.1
(Source 11.-61)

2.3.2 Riding Comfort Index

The Pavement Design and Evaluation Committee of the Canadian Good Roads Association developed the Present Performance Rating which was very similar to the PSR. The Present Performance Rating was changed to the Riding Comfort Index(RCI) in 1968 to denote the evaluation of riding quality only. The evaluation of the RCI is run basically

the same as for the PSR, but the RCI form has a rating scale from zero to ten for rating the riding quality. Figure 2.2 shows an example of the RCI form.[11]

Evaluation Form For RCI

```
10-¶-
   ¶
 9-¶ Very Good
   ¶                          Rater    ......................
 8-¶-
   ¶                      Hwy.   No.   ......................
 7-¶ Good
   ¶                  Section  No.     ......................
 6-¶-
   ¶                        Date  ......................
 5-¶ Fair
   ¶
 4-¶-
   ¶                    Is Pavement of Acceptable Quality?
 3-¶ Poor
   ¶                          Yes            ......
 2-¶-
   ¶                          No             ......
 1-¶ Very Poor
   ¶                          Undecided      ......
 0-¶-
                    Remarks..............................
```

Figure 2.2
(Source 11.-61)

2.3.3 Present Serviceability Index

When the Serviceability Index is mechanically measured it is referred to as the Present Serviceability Index (PSI). The PSI is the mechanical rating which is correlated to the PSR by calculating values with a regression analysis. There are many different machines to measure roughness. Two common machines are the Mays Meter and the Bureau of Public Roads type of roughometer (BPR roughometer).[12]

2.2.4 Mays Meter

The Mays Meter electronically records data for interface with a computer and can easily be mounted on an automobile. A schematic is shown in Figure 2.3. The Mays Meter measures the vertical deviations between the body of the automobile and the center of the rear axle in units of inches per mile. Although these measurements are objective, they will vary from year to year depending on the automobile's suspension. The rating vehicle should also be driven at a constant speed, so logically, measurements should be taken during off-peak traffic hours. The advantages of using the Mays Meter include:

- Operating speed is approximately that of normal traffic.
- Relatively low cost of operation.
- Capability for mass inventory basis.
- Instant records.
- Reasonably good repeatability of results.

Disadvantages are:

- Need for frequent calibration.
- Numerous operating precautions.
- Inability to measure large wavelength variations.[13]

2.3.5 BPR Roughometer

The BPR roughometer simulates one wheel of a passenger car and is usually mounted on a trailer. A schematic of the BPR is shown in Figure 2.4. It consists of a mass, spring, and damper combination. The displacement of the wheel is

MAYS METER

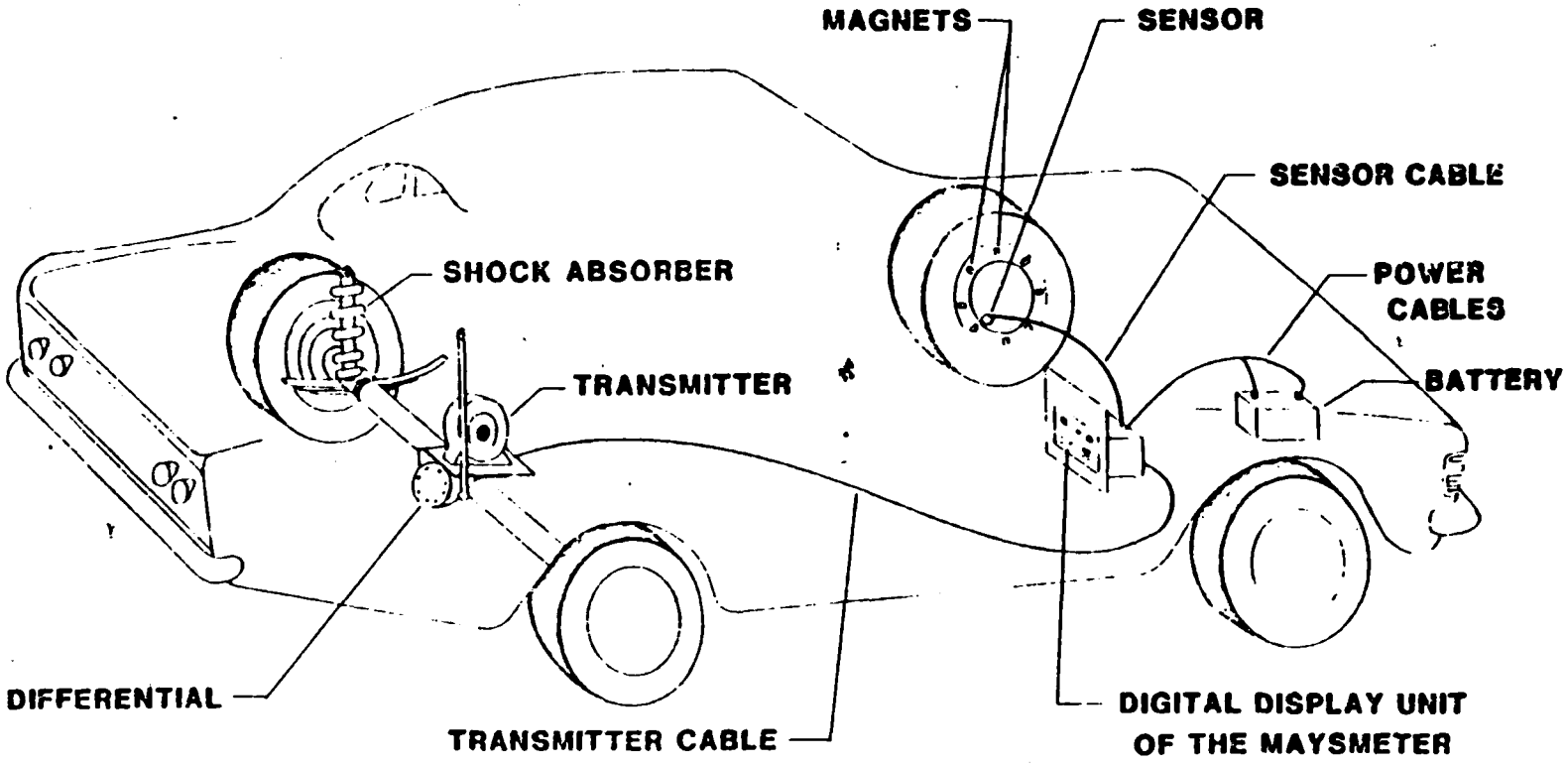


Figure 2.3
(Source 14.-41)

BPR Roughometer

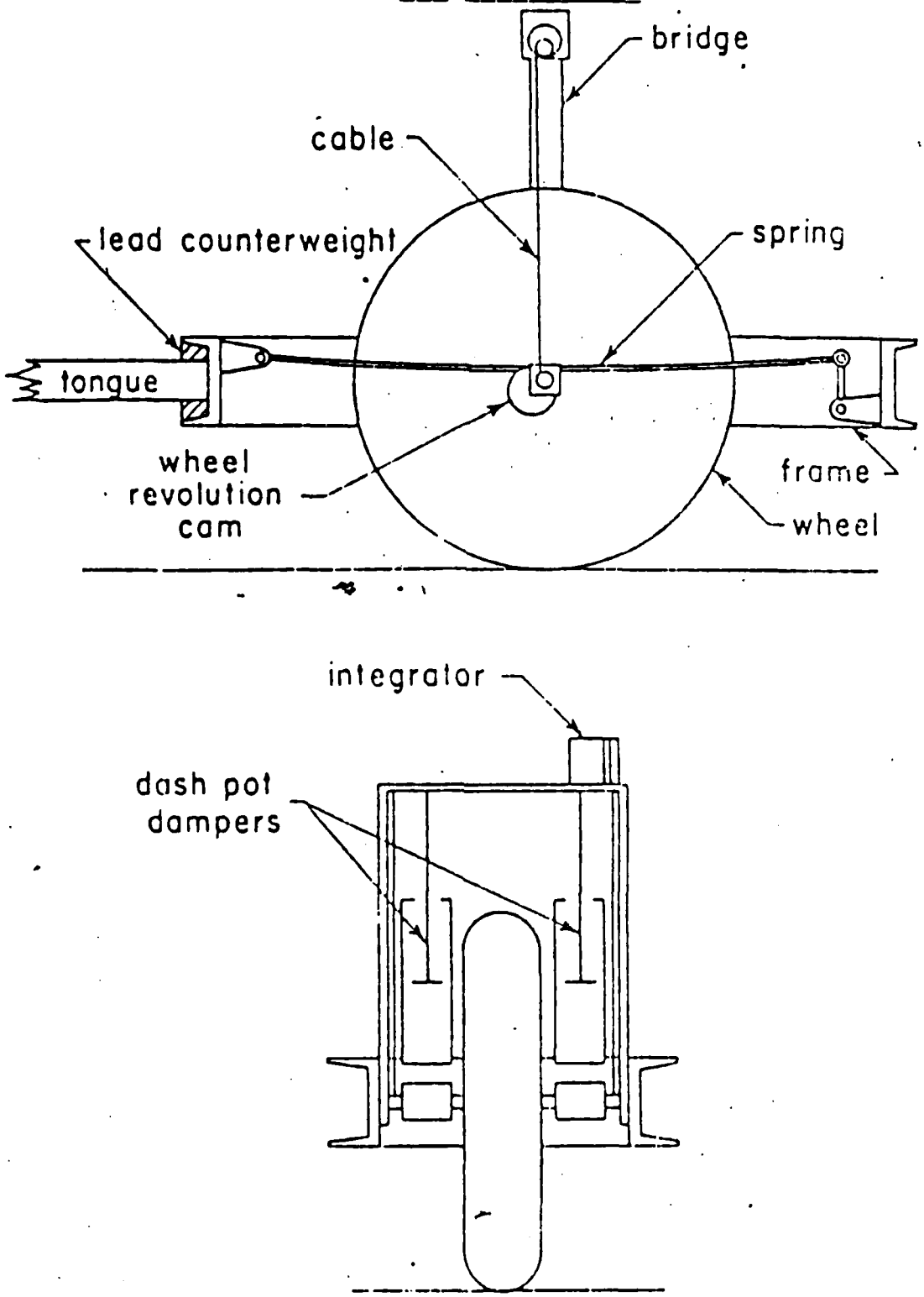


Figure 2.4
(Source 14.- 27-21)

measured with respect to the mass and is recorded by an integrator coupled with an electric counter. The counter records inches of vertical movement of the axle relative to the top of the suspension system. The measurements are accumulated and recorded in units of inches per mile. The advantages of the BPR roughometer are:

- Relatively low cost and ease of operation.
- Capability of mass inventory basis.
- Successful correlation with other instruments.

Disadvantages are:

- Low operation speed (approximately 20 mph).
- Poor repeatability of results due to calibration.
- Attenuation of wavelengths in the ride frequency range.
- Inability to measure large wavelength variations.[15]

2.4 Performance

There are other rating methods and numerous methods of measuring road roughness, the use of which help to evaluate pavement performance.

One of the functions of the PSR and PSI is to take the individual bias out of the assigned rating. Using this method of evaluation, an engineer can obtain measurements at various times and define pavement condition in design equations. The pavement manager can record histories of serviceability to define the pavement performance.

Whereas serviceability measures riding quality at a specific point in time, pavement performance is an accumulated measure of serviceability plotted over a period

of time. The PSR is used to measure serviceability on a scale to one to five, with five being an excellent pavement. Common terminable serviceability values are 2.5 for main roads and 2.0 for secondary roads. This makes sense because less tolerance can be tolerated on high speed roads than on secondary roads with low traffic volume. Figure 2.5 is a graphical representation that shows the serviceability of an average flexible pavement with respect to time.

The Serviceability-Performance Concept

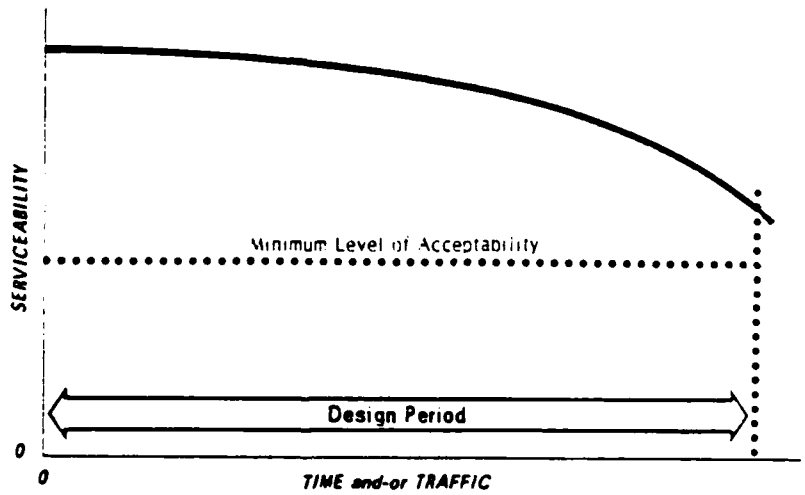


Figure 2.5
(Source 11.-58)

2.5 Pavement Condition

Pavement condition evaluations also need to be performed on pavements to identify pavement distress at a particular time. Pavement distress is an indication of structural or material defects that could lead to reduced performance or failure. As with a low PSR, pavement distress can also lead to an evaluation of structural

capacity, generally depending on the severity. As with any structure, a pavement can fail either functionally or structurally. A functional failure occurs when a pavement can no longer carry out its intended function, and thus is related to serviceability and roughness. A structural failure occurs when there is a breakdown in one or more of the pavement components, or a total collapse of the structure, so that the pavement is incapable of sustaining design loads on it's surface. The two types of failure do not necessarily go together, but often they do. Although certain types of pavement distress may indicate the reason for pavement failure (as discussed below), the condition survey should not be aimed at assessing future pavement maintenance needs to limit further deterioration or rehabilitation measures that need to be taken to improve the pavement. The condition survey is a qualitative and subjective rating when taken by an individual, that can be used to set up structural evaluation needs, priority ratings, and maintenance programs. It is an excellent management tool and at a minimum should include:

- The different types of distress.
- The location of distress.
- The degree of severity of each of each type of distress.[16]

2.6 Condition Surveys

There are numerous examples of condition surveys that can be used and each agency can design their own.

Basically, there are about five or six types of distress that are important for each type of pavement. The types of distress that give the local agency the most problems should be accounted for on the condition survey at a minimum. A distress survey form should have the important distress types noted with room to rate the severity of each and the percentage of area effected. Severity can generally be rated as high, moderate, or low. Weighted points can also be applied for different distress types and severity, to relate the condition of one section of pavement to another. The results of successive surveys can show a rate of change in conditions concerning a number of different factors.[17] Figures 2.6 - 2.9 are examples of distress survey forms.

2.7 Pavement Distress

The following sections describe some types of distress found in flexible pavements and rigid pavements. Distress can be categorized into three types of failure:

1. Cracking
2. Distortion
3. Disintegration

2.7.1 Flexible Pavement Distress

Cracking

Alligator or map cracking - usually occurs when one or more of the underlying layers experience excessive movement, or because of surface fatigue. This type of distress is recognized by a series of interconnecting cracks that resembles alligator skin.

Flexible Pavement Distress Survey Data Analysis Worksheet

(HEADER INFORMATION)

		Load Cracking Severity	Non-Load Cracking Severity	Deformation Severity	Material Related Surface Distress Severity	Repair Severity	
Sub Section	A	_____	_____	_____	_____	_____	
	B	_____	_____	_____	_____	_____	
	C	_____	_____	_____	_____	_____	
	D	_____	_____	_____	_____	_____	
Sum							
Weighting Factor		X (10)	X (5)	X (6)	X (7)	X (5)	Total of Weighted Sums (TWS)=
Weighted Sum (Product)							

$\Sigma DP = TWS \div 4 =$ _____

$PDI = 100 - \Sigma DP$

$PDI = 100 -$ ____ = [ ]

Figure 2.6
(Source 18.-41)

Rigid Pavement Distress Survey Data Analysis Worksheet

(HEADER INFORMATION)

		Joint Condition Severity	Cracking Severity	Surface Defect Severity	Patch Severity	
Sub Section	A		_____	_____	_____	
	B		_____	_____	_____	
	C	_____	_____	_____	_____	
	D		_____	_____	_____	
Sum						
Weighting Factor		X(40)	X(6)	X(8)	X(3)	Total of Weighted Sums (TWS)=
Weighted Sum (Product)						

ΣDP = TWS ÷ 4 = _____

PDI = 100 - ΣDP

PDI = 100 - ____ = [ ]

Figure 2.7
(Source 18.-42)

FLORIDA DEPARTMENT OF TRANSPORTATION
1983 FLEXIBLE PAVEMENT CONDITION SURVEY
(WORKBOOK--MTPCS23, FORMAT 1981 AHEAD)

CRD TYP	MONTH	YEAR	[illegible]	[illegible]	COUNTY	SECTION	SUB SEC.	STATE ROAD NO.	U.S. ROAD NO.	SYSTEM	ROADWAY	TYPE	BEGIN MILE POST	END MILE POST	NET LENGTH	AVERAGE DAILY TRAFFIC	SPEED	MAYS METER COUNT	ILRAANVEESL	CLS 1B	CLS 2	CLS 3	RUTTING	PATCH	REMARK
1	2 3	4 5	6	7	8 9	1 1 0 2	1 1 3 5	1 1 6 9	2 2 0 3	2 4	2 5	2 6	22 2 3 78 9 1	33 3 3 23 4 6	33 3 4 78 9 1	4 4 4 4 2 4 5 7	4 8	4 5 9 4	55 56	5 7	5 8	5 9	6 0	6 1	6 6 7 7 2 5 0 5
X	XX	XX	X	X	XX	XXX	XXX	XXXX	XXXX	X	X	X	XX.XXX	XX.XXX	XX.XXX	XXX.XXX	X	XXXXXX	XX	X	X	X	X	X	XXXXXXXXXXXXXX

Figure 2.8
(Source 19.-5)

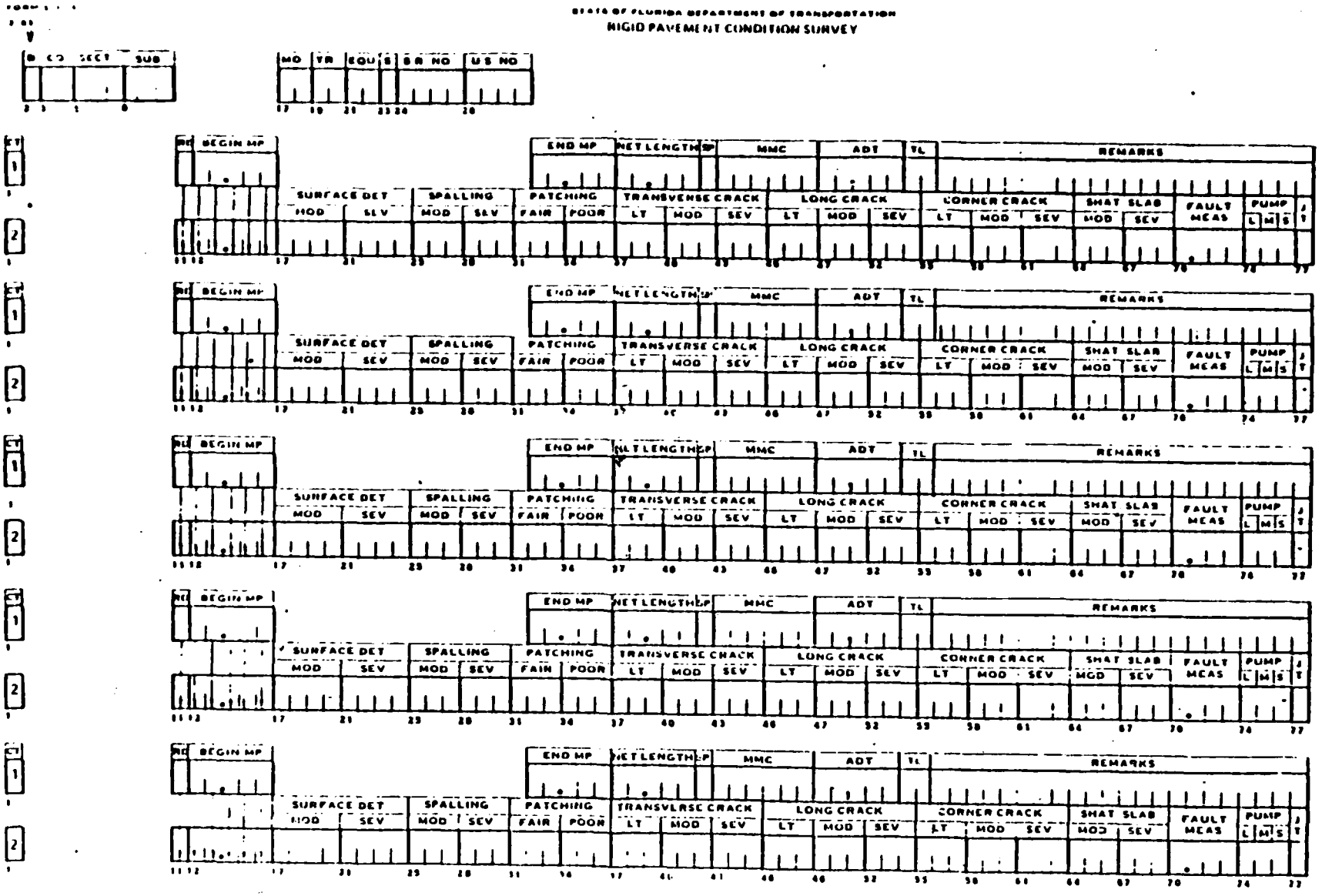


Figure 2.9
(Source 20.-5)

Longitudinal cracks - horizontal pavement movement caused by lack of internal friction in the base or subgrade. Cracks appear parallel to the pavement center line.

Slippage cracks - usually caused by a lack of good binding between the surface and course layers. Slippage appears as crescent shaped cracks that point in the direction of wheel thrust.

Reflection Cracks - when rigid pavements are surfaced with asphalt, cracks will appear at the location of the joints and cracks of the concrete pavement

Distortion

Rutting - surface distortion that can be caused by consolidation of one or more of the pavement layers. It is a surface depression in the wheel paths.

Shoving - caused by plastic movement of the pavement materials and forms ripples across the wheel paths.

Frost Heave-ice lenses form in frost susceptible soil and lift up sections of pavement.

Disintegration

Pot holes - caused by a number of reasons one of which can be a base failure. Typified by a bowl shaped hole in the pavement.

Bleeding - can occur for a variety of factors including too high of an asphalt content in the mix, soft asphalt type for climate, consolidation of the surface, and other reasons. Asphalt is pushed to the surface which lowers the skid resistance.[21]

2.7.2 Rigid Pavement Distress

Cracking

Transverse Cracks - Transverse cracks are long cracks that occur perpendicular to the center line. They can be caused by the loss of subgrade support from pumping, or by excessive slab contraction, or by the slab warping.

Longitudinal Cracks - Longitudinal cracks appear as long cracks parallel to the center line of the pavement and occur because of the warping or base failure. They generally occur when pavements are constructed without longitudinal hinge joints and are sometimes referred to as warping cracks.

Corner Cracks - Corner cracks occur at the edge of the slab because of base failure.

Distortion

Faulting - Faulting nearly always occurs in the slab ahead of the traffic due to load transfer. It is the difference of elevation across a joint or crack.

Pumping - Pumping occurs mainly because of excessive hydrostatic pressures. The excessive pressures fine base and or subbase material to be forced through the joints or cracks.

Disintegration

Scaling - scaling can occur due to numerous reasons including wet mixes, dirty aggregate, and chemical treatments such as salting the road in the winter. Scaling appears as shallow cracks which break up the concrete at the surface.

Blowups - Blowups occur at a pavement joint on the concrete pavement due to compressive stresses, particularly if joints become clogged with sand or other fine incompressible material. Blowups are either upward movements or the shattering of pavement slab edges.

Spalling - Spalling is the cracking, chipping, or the break up of the concrete at the slab edges. It can occur from the deterioration of concrete due to the material quality or excessive stresses.[22]

2.8 Structural Capacity

The structural capacity of pavements also need to be evaluated to estimate the load carrying capabilities of existing pavements or to estimate the future service life of the pavement considering the expected traffic loading. It is usually performed to determine the reason for the current condition of the pavement. A very poor serviceability, or the presence of pavement distress usually indicates a poor structure and the need for a structural survey. There are both destructive and non-destructive methods for evaluating the pavements structural capacity. Regardless of the method, certain characteristics of the pavement need to be measured or monitored. The most common characteristic used is the pavement deflection with regards to applied loads. The deflection levels then can be used to determine the stiffness values or the strength of underlying layers or the subbase. The advantages of destructive testing must be weighed against non-destructive testing.

2.9 Nondestructive Testing

The different tests are deemed nondestructive because an unlimited number of tests can be taken at the same location. Nondestructive testing methods measure either a response to a static load or slow moving load, response to a repeated or dynamic load, or a response to a controlled radiation source. These measurements are taken at or near the surface of the roadway and related to the structural properties of the pavement section. Nondestructive testing then requires some knowledge of the existing pavement with regards to the layer types and thicknesses.

The most common measured response is to a static or slow moving load. This method most closely simulates a heavy moving wheel load. Many factors influence the deflection of a pavement under a load, including temperature, moisture content, and the relative stiffness of the pavement itself. The testing technique has been standardized by different agencies using different pieces of equipment, but virtually all use the same concept. The Benkelman Beam may be the most popular.[23]

2.9.1 Benkelman Beam

The Benkelman Beam is a simple hand-operated device that consists of a simple lever arm attached to a light frame. The test is run by placing the probe point of the beam between dual test tires and the motion of the beam is recorded on an Ame's dial. Figure 2.10 is a schematic of the Benkelman Beam. The Ame's dial can record deflections

Benkleman Beam

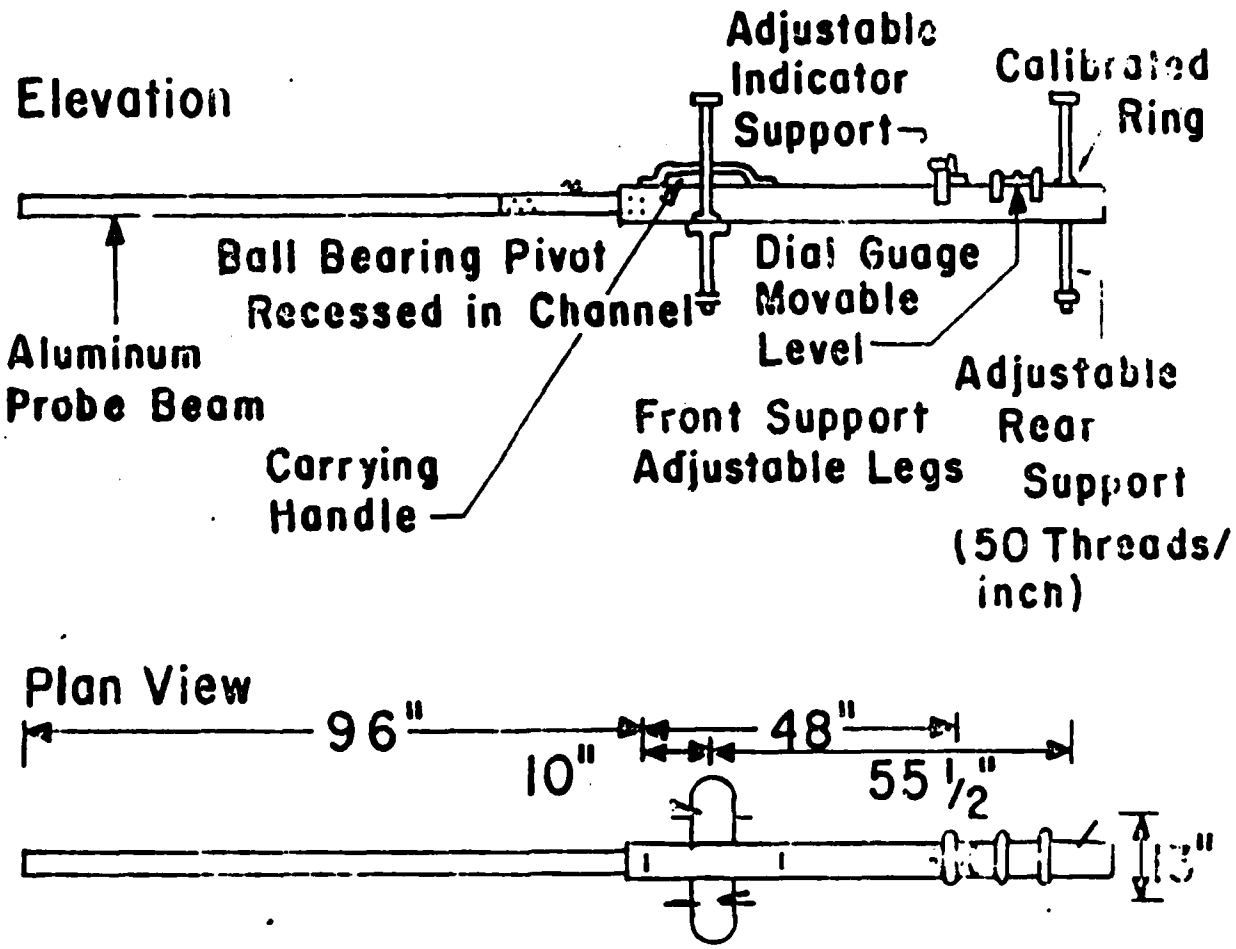


Figure 2.10
(Source 14.- 40-11)

up to .001 inches. An 18-kip single axle test truck is generally used with the test. This method is relatively simple, versatile, and inexpensive.[24]

2.9.2 Dynaflect

The dynaflect measures deflection on the principle of a vibratory force that is placed on the pavement by means of two small metal loading wheels. Two unbalanced fly wheels, that rotate in opposite directions at 480 rpm, produce a cyclic vertical force of approximately 1000 pounds on the loading wheels. The amount of deflection is detected by sensors (geophones) which are placed at specified distances ahead of the deflection wheels. Figure 2.11 is a schematic of the dynaflect. Because of the small load placed on the pavement, this test method is usually correlated with Benkelman Beam.[25]

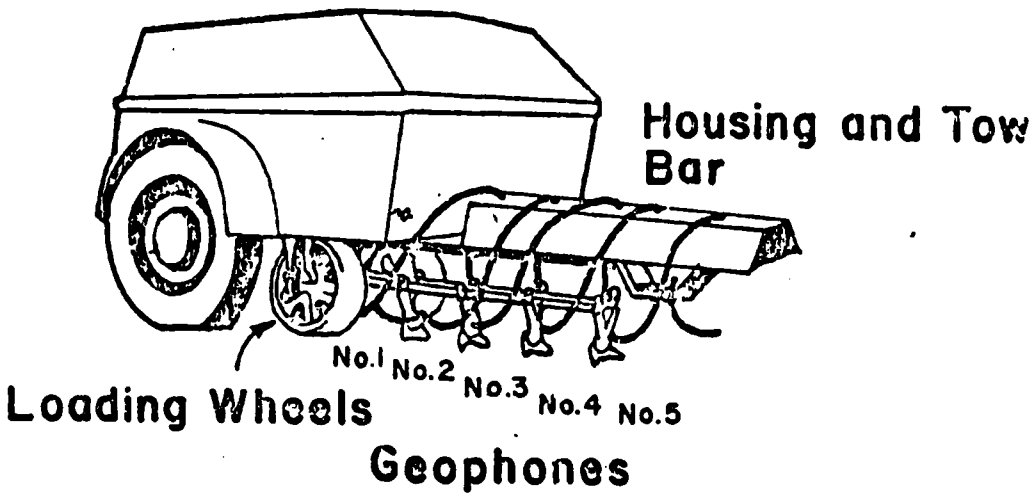
2.9.3 Nuclear Devices

Nuclear radiation tests generally can estimate the density of the underlying materials. The depth of the nuclear response is shallow. Equipment, such as the nuclear densometer, is generally used in the evaluation of individual components or layers, primarily during the construction phase.[26]

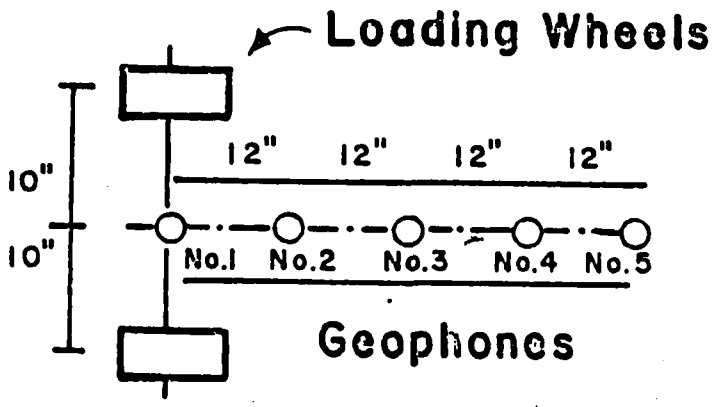
2.10 Destructive Testing

Conditions of pavements can be evaluated with accuracy using nondestructive tasting procedures, but sometimes too much reliance can be placed on surface deflections, which can yield misleading results. Sometimes it becomes

Dynaflect



(a) the Dynaflect system in operating position.



(b) configuration of Dynaflect load wheels and geophones.

Figure 2.11
(source 14.- 40-15)

necessary to test using destructive measures to ascertain the exact location of the failure, and the cause of it. The term destructive testing is used because once these methods are used, the original structure of the complete pavement is destroyed with respect to future testing at the same location. As a general rule, destructive testing is not used unless there is pavement distress in the section. One method of destructive testing consists of coring and removing samples of the different components of the pavement and the subgrade, and testing the samples in a laboratory to determine the load carrying capacity of the road way. Another method is to excavate test pits for field testing such as the plate bearing test or field California Bearing Ratios (CBR).

The advantages of destructive testing methods should be compared to nondestructive testing methods. Destructive methods allow for detailed observation below the pavement surface which is ideal, but patching is necessary and the procedures take more time to complete and are generally more expensive.[27]

2.11 Skid Resistance

Skid resistance is very important for safety purposes. The pavement needs a certain resistance to sliding or the skidding of the vehicles. Skidding is a sliding motion with the wheels in a locked position. Hydroplaning is also important and refers to the action when the wheels of the vehicle actually lose contact with the pavement surface because of a film of water between the wheel and the

pavement.

As one can imagine, there are numerous factors which influence skid resistance, including the pavement surface characteristics, driver reaction and abilities, and the vehicle characteristics. Many different vehicles travel the roads today and all have different characteristics. Vehicle weight, wheel base, wheel width, tire tread and pressure, and many other vehicle characteristics vary greatly between vehicles and all influence skid resistance. therefore, skid resistance is generally measured using a standard vehicle and can be evaluated as a skid number based on the coefficient of friction.

The most common method is ASTM method E274. This method uses trailers in which the wheels can be locked. Trailers are towed at 40 mph and the wheels are locked and allowed to skid for a distance. The force of the skid wheels are then measured and a skid number is calculated for that particular test section of pavement.[28] See figure 2.12 for a picture of a testing trailer in operation.

There are numerous other test methods and many can be correlated with one another. As with other evaluation measurements, the skid resistance can be measured over a period of time and under different conditions to aid in the future rehabilitation needs of the pavement.

In addition to skid resistance, there are other factors that influence road safety that need to be evaluated periodically, especially when the traffic volume increases.

Certain types of pavement distress, such as pot holes or rutting can present enormous problems with respect to safety and attribute to traffic accidents. Pavement width and shoulder width may be under designed for the current traffic level. Trees and other objects too close to the road as well as over hanging tree limbs and falling rocks may also present a safety hazard. Road markings and delineations are important. These factors and more all must be taken into account when developing strategies for pavement maintenance. Safety has become increasingly important in the world today, with the possibilities of large lawsuits filed for negligence.

Skid Test Trailor For ASTM Method E274

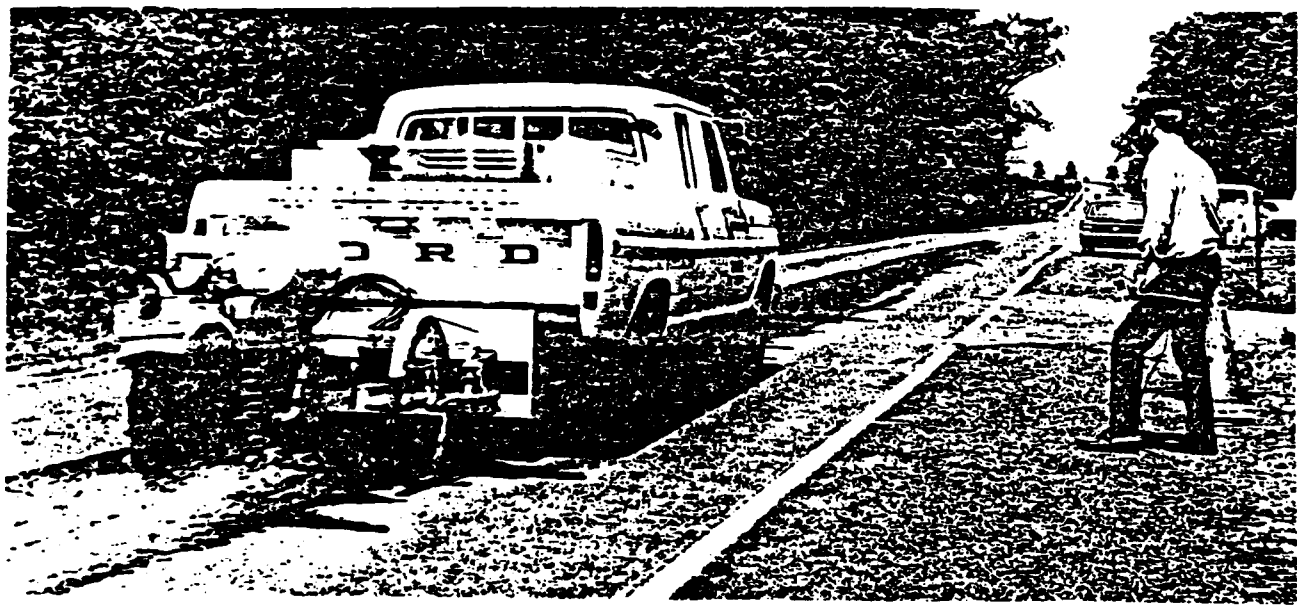


Figure 2.12
(Source 11.-13)

CHAPTER 3
INVENTORY AND ORGANIZATION OF DATA

3.1 Inventory

A pavement manager needs to know exactly what he is managing. He needs to know what types of pavement exists, how much of each, and the condition. Inventory is nothing more than a physical accounting accounting of the assets of the particular road system in place.

Before undertaking an inventory, it should be well planned. Planning can eliminate or help to limit mistakes and oversights. A plan can also help to condense work and save money. For example, two items can be accounted for with one inventory, instead of holding two separate inventories. Also, if data is already available , there is no reason for another inventory except for simple verification. The best way to manage a road system may be by sections, thus the inventory can be taken in sections. Sections allow for the road system to be managed by smaller subsets. A manager can get overwhelmed by too much information and sections allow the manager to digest smaller amounts of information in an orderly arrangement. The smallest number of sections would be best for management purposes. Sections can be defined many different ways, but they should always be defined so that the section is consistent with regards to the physical characteristics and the factors which attribute to deterioration.

Some examples of factors to take into account when defining sections are:

- Geographical boundaries such as rivers or lakes.
- Town or county or other property lines.
- Change of pavement type or structure.
- Change in number of traffic lanes.
- Change in natural subgrade characteristics.

The goal should be to document the inventory in a clear and organized manner so that the information can be easily recalled when needed. There is a lot of information that can be compiled for the management of the system. Typical items that are accounted for are:

Section Number and Description- includes the name or route number of the road

Road Classification- federal or state aid roads should be signified and whether or not the road is an emergency route, transit bus route, scenic route, or other comparable designation.

Traffic- traffic loadings are very important, especially if there are significant growth trends. Average daily traffic should be recorded and the percent of truck traffic as a minimum.

Geometry- include pavement width, median width, shoulder width and type, side-slopes, superelevation, number of lanes, provisions for parking, guardrail locations, and sidewalk locations.

Cost Data- pavement cost and maintenance should be recorded

Historical Data- a good inventory and monitoring system will have much historical data available on streets. Historical data gives an excellent picture of what types of construction and maintenance have worked or failed in the past and can be used as a learning tool. Historical and current data can also be used for documentation in budget submittals.

Numerous other data that should be recorded and documented, but not as important include:

- The location, placement and description of lighting, other utilities, signs, and pavement markings.
- Right of way locations and boundaries.
- Various other items.[29]

3.2 Organization of Data

Once inventory and evaluations have been made, the information needs to be properly documented and organized. A Pavement Management Information System (PMIS) is any established documenting procedure for collecting and storing, processing, and retrieving information. A simple method to use can be the color coding of maps to show the condition of all road sections and the type of roads. An inexpensive personal computer can handle just about any inventory format with the data easily retrievable. Large amounts of data can be quickly manipulated which would make a computer system desirable, but not a necessity.

A proper inventory should include as much pertinent information as possible, but not too much. In addition, the entire area under the pavement manager's responsibility

should be broken down into sections for easier management. Items include: street classification, pavement structure, history, cost data, traffic loading, geometry, drainage characteristics, and other factors.

Pavement distress and condition surveys should, at a minimum, define the type of pavement distress or deficiency, list the degree of severity, and show the percentage of the area affected. Codes can be used to show which streets or roads need:

1. No maintenance.

2. Minor or routine maintenance or expedient expenditure.

3. Require preventative maintenance such as a seal or asphalt overlay, etc...

4. Major rehabilitation or reconstruction, i.e. it is no longer cost effective to initiate routine maintenance and the road needs major work to be acceptable.

The popularity of computerized Pavement Management Systems is increasing. PAVER is an example of a computerized distress survey and management system. PAVER was developed by the U.S. Army Corps of Engineers for use on military bases. It can also be used mechanically. As any computer program though, it's only as good as the information which is inputted. Competent people still need to enter the condition survey data consistently, or insure that this is done.

CHAPTER 4
ANALYZING PAVEMENT DATA

4.1 Pavement Maintenance Strategy

Together with a good inventory, evaluation, and condition survey, management will have the best available information upon which to analyze and make a decision. Generally the evaluations are done by section on the project level and then incorporated into the whole system network. The analysis of data will determine the maintenance and rehabilitation required in a certain time frame. The analysis will be based on a certain set of standards and coupled with engineering judgement. The purpose of the analysis is to identify the cause of each measured distress or deficiency and to recommend maintenance alternatives for corrections. Pavement maintenance is defined as the work required to delay the deterioration of the pavement condition or to restore the road to a condition appropriate to its past level of service. The most proper preventive maintenance strategy should be determined. A pavement strategy is the planned program action which is most appropriate for the condition of the pavement. As mentioned before, maintenance dollars should only be spent on those sections of pavement that are in good enough condition to warrant such an expenditure.

Pavement maintenance is required for the following reasons:

- To improve the level of serviceability and riding comfort.

- To improve the level of safety, either by treating the surface to improve skid resistance or to improve rutting conditions.

- To counter structural distress or deterioration.

- To remedy inadequate structural capacity to increase the traffic bearing capacity.

For each reason maintenance is required, there may be a number of different treatments that can be used. An alternate list of treatments should be devised and then alternate strategies can be selected.[30]

4.2 Alternate Strategy

Whatever the reason for required maintenance, a considerable list of alternatives may be produced. If the managing agency has had success with an established program, then some alternatives may be disregarded from the beginning. For example, if the agency knows that a specific material is unavailable in the area, or the cost is exceedingly high, an alternative which uses that specific material may never be deemed an alternative. Another example may be that if the agency has a standard practice that works well and construction crews have expertise with that practice, then the agency may decide to stay with the methods that have worked well in the past and not bother to examine other viable solutions. Historical records or knowledge may be used in this process and can be very valuable. However, even though past methods have worked well for an agency, new methods and materials should be

examined for feasibility.

Reusing in-place materials in alternative strategies should be a priority because of the potential cost savings. Recycling asphalt pavement is becoming more popular. Pavement surface recycling has been used primarily for conserving in-place materials and energy, and for reducing cost for correcting surface deficiencies of skid resistance, deformation, and cracking. Present pavement surface recycling is becoming a procedure that involves pavement and materials evaluation, material proportioning, and construction controls.

The first step in listing alternative pavement maintenance treatments is to list major alternative treatments first, in order to use as a guideline, and then specific alternatives for each pavement section. The five major alternatives are:

1. Postpone treatment, continue routine maintenance.

2. Rework of in-place materials, will improve riding quality and possibly safety.

3. Surface dress, will seal pavements and improve skid resistance.

4. Overlay, resurface, or reconstruction, increases structural capacity and improves riding quality and skid resistance.

5. Strengthen base, subbase, or subgrade by improving drainage.[31]

The following are examples of specific alternate treatments that can be listed for the following pavement

maintenance need; riding quality, safety, or strength:

List of Alternatives to Improve Safety

- Postpone treatment.
- Surface treatment (various types).
- Resurface with friction course.

List of Alternatives to Improve Riding Quality

- Postpone treatment.
- Rework the materials in-place, with or without additional wearing course or surface treatment materials.
- Leveling course and surface treatment.
- Heat, plane, and resurface.
- Milling operations and recycle.

List of Alternatives to Improve Pavement Strength

- Postpone treatment.
- Full depth patching and surface treatment.
- Full depth patching, leveling course, and resurface.
- Improve drainage.
- Reconstruction.
- Overlay.
- Milling operations and recycle.[32]

These examples show that there are numerous maintenance alternatives to correct deficiencies. These lists are by no means complete and some viable solutions may incorporate two or more of the individual examples. For example, drainage may be improved and an overlay may be placed to increase the structural capacity of the pavement. Each alternative also

may have many different factors involved, so the optimum design should be selected for each individual alternative first, befor comparing against other alternatives.

4.3 Five Basic Maintenance Strategies

Specifically, there are five basic actions or maintenance strategies that can be considered for pavements:

1. Routine Maintenance

This is generally the most cost-effective use of funds for roads in good condition. Maintenance includes local patching, crack sealing, and other small actions. Funding should be done annually and the larger or more severe distresses should be dealt with first.

2. Preventive Maintenance

This action is used to prevent more serious distresses from becoming even a larger problem. Extensive repair work may also be included. Surface sealing is an example of preventive maintenance and repairs usually need to be programmed and made over a period of several years in order of priority because of the higher expenses. Routine maintenance should be performed if maintenance is not scheduled the current year.

3. Deferred Action

These sections are beyond the point where preventive maintenance will be effective, but don't need rehabilitation. Funds and a program should be set up to rehabilitate at the appropriate time.

4. Rehabilitation

Usually rehabilitation requires overlays or recycling. Established priorities should be followed and if funding is short this action is usually deferred.

5. Reconstruction

This action is basically the same as rehabilitation except the costs are higher. It involves the complete removal and replacement of the existing pavement and sometimes widening and expanding and adding traffic devices. It is usually programmed for five to ten years because of the costs and the scope of the work.

While analyzing some pavements, there may be a pavement which falls on a point between one of the above strategies. When this happens, one can always look at the factors which governed the condition rating. For example, if the surface distress such as weathering, ravelling, or bleeding governed, then preventive maintenance may be chosen as the strategy. If alligator cracking, pot holes, or failed sections governed, then a rehabilitation effort might be better planned and preventive maintenance funds not wasted.[33]

CHAPTER 5
DECISION OF ALTERNATIVES

5.1 Decision Factors

Many different factors need to be weighed before choosing an alternate repair or maintenance strategy. The costs that need to be considered are many. Costs for construction, annual routine maintenance, major repair, user cost due to current pavement conditions, user cost due to delay during rehabilitation or reconstruction, the salvage value at the end of the consideration period, and many other costs should be examined.

Because limited funds usually make it necessary to rank desired projects, proposed projects need to be prioritized. This is not at all easy because the pavement manager needs to balance many different costs and factors to rank priorities and some factors are difficult to quantify. Decisions are often based on the findings of the condition surveys. The distress surveys can compare different sections of pavement with regards to their condition. The structural evaluation may show one section has a larger structural deficiency even though the distress is not as bad. The skid resistance may be so low that immediate attention is required for safety reasons. Traffic patterns, loadings, and quality control items may effect the materials used in the maintenance treatment. Some alternatives may be chosen over another, or a different design strategy used because of material availability. Utilities should always be coordinated with pavement projects to save effort and

costs. It may be wiser to delay some maintenance actions if utility work beneath the pavement is to be undertaken and completed in the near future. There are many different factors that need to be weighed before choosing an alternate strategy.

Some factors, like construction costs, are easy to quantify and others such as user costs are not, but all factors need to be quantified to compare alternatives. The following list is an example of some of the factors which are taken into consideration when selecting alternatives.

Construction Costs

- Initial capital construction costs.
- Future capital cost of construction or maintenance.
- Future maintenance costs.
- Salvage value at end of design life.
- Engineering and administration cost.
- Cost of investment .

User Costs

- Running user costs (operating costs).
- Added user cost (cost for delay of traffic).
- Discomfort.
- Environmental influences.

Other Factors

- Load carrying capacity.
- Rate of deterioration under traffic.
- Level of safety.

5.2 Economic analysis

Once different alternatives have been selected for each project, they need to be compared and prioritized. There are several economic analysis methods to do this. Three different economic analysis methods which can be used are:

1. Annual Cost Method - This method considers all costs and benefits involved in each alternative as equivalent series of periodic payments. Usually the period selected is yearly, although other periods can be used just as well. The annual costs of alternatives can then be compared.[35]

2. Present Worth Method - This method considers all costs and benefits as a present value. Alternatives are then compared on the basis of equivalent present worth. This method can be used by comparing costs, benefits, or a combination of the two.[36]

3. Benefit/Cost Analysis - This method is often referred to as the benefit/cost ratio method and is probably the most common method used today. Although future worth and present worth comparisons can be made with this method, it is most commonly used to compare the annual worth of the benefits of a proposed alternative to the annual worth costs. An alternative with a benefit/cost ratio greater than 1.0 has more benefits than cost. Alternatives can be ranked according to their ratios. The alternatives with the higher ratios would generally be the better choices.[37]

All three of these methods utilize the time value of money concept and are very useful, but they have

limitations. Certain factors are subjective and assumptions need to be made about the future, so results need to be put in perspective. Some basic principles that are applied when using an economic analysis are:

- All alternates need to be compared over the same time period.

- Evaluation should include all possible alternatives. Alternatives need to be compared with each other besides a base or existing situation.

- Analysis provides information for a management system, and does not represent a decision by itself.[38]

5.3 Ranking Projects

Once different alternatives have been selected for each project, the different projects themselves need to be compared and prioritized. There are several methods which can be used to do this. An economic analysis of some sort is usually run, as discussed in the previous section, or a formula type method can be used.

5.3.1 Formula Method

Rating methods can take into account different factors. A relatively simple method to use and easy to adapt to agency needs is by using a Priority Index. This method assigns a numeric value to a road based on road surface conditions or distress. A high index would indicate a higher priority. A number of different multipliers can be applied to the Priority Index to account for a variety of different factors. A traffic volume multiplier can be used

to consider low or high traffic volume which should have an influence on the priority. Route classification may also be important and weights can be assessed depending on whether the road is a minor or a major route or if it is a bus route, emergency route, or other route which may need specific attention. Maintenance history can also be accounted for where routes with historically high maintenance costs would have a higher multiplier assigned. After all multipliers are assigned and the calculations completed, projects are ranked according to their priority index. The classification of the road needs to be looked at carefully when using this method because the lower class roads may never make it to the top of the list.[39]

5.4 Deferred Maintenance

The most important factor when ranking may be the added cost of deferred maintenance. The deterioration of pavements is not a straight line relationship with respect to time. The quality or serviceability of different pavement sections will vary over time, but generally, deterioration of pavement quality increases dramatically beyond certain point in time, due to the compounding effect of pavement distress. Figure 5.1 shows that there is a short period of time where if preventive maintenance is deferred, the cost of rehabilitation increases dramatically. Especially if maintenance is deferred so long that reconstruction is necessary vice rehabilitation methods.[41]

The Cost of "Timely" Maintenance

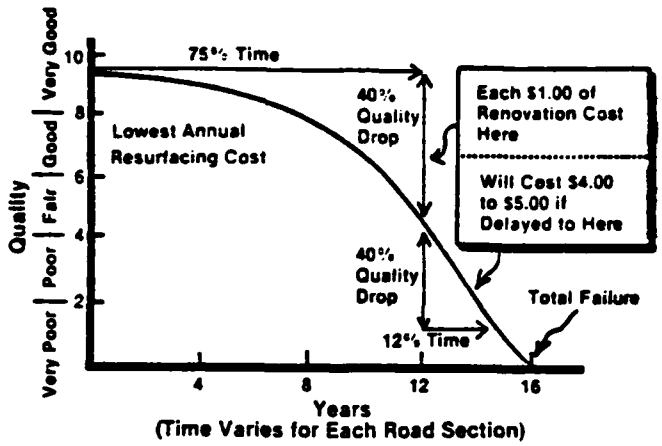


Figure 5.1
(Source 40)

CHAPTER 6
IMPLEMENTION OF DECISIONS

6.1 Implementation

There are two basic phases in the implementation of pavement management, the detailed planning and design phase and the construction phase. These phases are carried out at different management levels. The project management level would be the design and construction of one project only whereas the central management level deals with the coordination of the various projects and the whole agency program.

6.2 Plan and Design

The first step in the implementation of design strategies is the actual planning and detailed design of the project, especially for a new road or major rehabilitation or reconstruction project. Generally routine maintenance requires minimum or no design effort. Routine maintenance follows procedural guidelines and requires an effective program set up for the scheduling of work and leveling of agency resources.

Today, standard designs are used for overlays or entire pavement design by many agencies. A standard design lowers design cost and does not require as much expertise as conventional design, but sections may be under designed or over designed in some areas which will probably cost more in the long run. If the agency does not have the in-house capabilities or resources for design, it may be contracted out to private enterprise. If this is the case, the agency

needs to work closely with the designer in order to insure the design incorporates all the desires of the agency. This is very important because of the many different conditions that should be accounted for in the planning and design of a project. Although most important for new construction, many of these conditions or factors effect maintenance projects also. When design is contracted out, the agency loses some control of the design, so communication with the designer is very important. Conditions that should be checked when designing a project include economics, environmental and social impact, labor and material availability, and maintenance and construction techniques. Agency input on past pavement failures and construction methods can greatly improve a design. In addition, a design can be developed from different perspectives. One design may be planned to minimize construction costs where another design may maximize the pavement life.

6.3 Construction

Each agency needs an excellent construction program to carry out the pavement strategy chosen. Construction can be carried out using either in-house resources or it may be contracted out. Regardless, the agency needs a construction management program to insure the project is built within the budget and time allocated and with built-in quality. If work is done in-house, a project manager should be in charge. A construction manager may be in charge of one or more projects. If the project is contracted out, then the agency should have a construction contract administrator in charge.

6.3.1 Construction management

The construction or project manager is concerned with completion of the project on time, while controlling the budget and quality. In order to be successful, the project manager should be current with scheduling techniques, production rates, equipment operations, construction techniques, safety, and many other factors involved with construction operations. An excellent project manager is invaluable to an agency because they actually experience, measure, observe, document, and report "as built" conditions on a project by project basis. They provide most of the basic construction information on the pavement network. The value of historical information was discussed previously. By documenting maintenance and construction techniques with "as built" conditions, they can be compared to pavement failures in the same section and help to make better future decisions on designs and construction methods. Effective management thus depends directly on the collection and collation of reliable data.

6.3.2 Construction Contract Administration

The administration of construction projects should achieve the same end result as the construction manager. The difference is that the contact administrator does not have direct control over the construction force, but insures a successful project by working with the contractor. He is responsible for completing the project on time, with good quality, and under budget, the same as the construction manager. Usually the contact administrator has an

inspector to insure quality and to verify the work completed. He also pays the contractor for the services rendered. An excellent construction management program, including inspections and quality control, can save numerous dollars and prevent hardships. Planning and insight can help a project to run smoothly and limit the delays and inconveniences. If the decisions are not implemented correctly, then all the work of the previous four activities of pavement management can be diminished.

CHAPTER 7
PAVEMENT MANAGEMENT SYSTEMS

7.1 Functions of Pavement Management Systems

Pavement Management consists of five major functions. A Pavement management System(PMS) is an established, documented procedure treating one or more of the pavement management functions in a systematic and coordinated manner. A PMS has five basic components that relate directly to the five functions of pavement management.

1. Pavement Condition Survey.
2. Data Base Containing All Pavement Related Information.
3. Analysis Scheme.
4. Design Criteria.
5. Implementing Procedures.[42]

A PMS can identify optimum strategies at the different levels of management which can be implemented to provide and maintain pavements at an acceptable or adequate level of service. Most PMSs are computer based filing cabinets and data retrieval centers. The reports and programs generated supply information on qualitative pavement conditions, which must be coupled with quantitative data, further information, and engineering judgement for action and implementation.

7.2 Two Levels of PMS

As pavement management deals with different levels of management, a PMS can be a project level system or a network level system. A PMS can actually handle both levels of management, as the level of management only deals with the

particular information which is evaluated.

7.2.1 Project Level PMS

A project level PMS evaluates relatively short pavement lengths. A complete evaluation is usually performed on all sections of the road. This gives a detailed profile of the road which may be used for budgeting purposes or to aid in the selection and design of 43 maintenance strategies.

7.2.2 Network Level

Network level evaluations are performed on longer units of pavement and taken as a sampling approach. A random selection may be used to determine test units (about 15-20% of a pavement section) and information is extrapolated for the whole section. Another approach is to perform a less detailed evaluation of the entire road system. A complete evaluation is usually performed on all the sections of the road. With this method, a slow moving vehicle can obtain a surface rating condition. A system can also use both previously described methods. A PMS is more beneficial if the network level information can be useful, viable, and conclusive input for the project level decision phase. The network level data can serve as good supplementary project level input.[44]

7.3 Benefits of PMS

The systems method of pavement management is a comprehensive problem-solving process. The Technology of computers has enabled large amounts of information to be

stored and complicated calculations to be completed in seconds. Using management input such as performance, policy, and budget coupled with engineering inputs related to current conditions, relevant cost and performance models, a system can be achieved which consistently details the most cost effective maintenance and rehabilitation policies.[45]

CHAPTER 8
PAVEMENT DESIGN

8.1 Overview of Pavement Design

The pavement design process has evolved over the years and changes continue to occur in the methods. For years engineers only used rule-of-thumb measures for pavement design. The Highway Research Board was organized in 1920 and a major effort to improve pavement design was undertaken. A variety of theoretical and empirical studies have been performed. Numerous information was obtained by building test roads or sections of test road of both asphalt and concrete. The most famous may be the AASHTO Road Test which was constructed in the 1950's in Ottawa, Illinois. Major findings included the effect of relative pavement thickness on performance. The results have been a major influence in today's pavement design concepts.

Many factors have to be taken into consideration when designing pavements and there are many different pavement design methods available to engineers today. This chapter will discuss many of the popular methods to familiarize the reader with the approach of each. While examining pavement design methods, one can see the many different factors that are or are not taken into account for both flexible and rigid pavements. A pavement design will consist of the actual structural design of the different components and the design of the pavement mixtures.

The capacity of a flexible pavement depends on the load distributing characteristics of the layered system. Figure

8.1a illustrates the different layers or components of a typical section of a flexible pavement.

Pavement Types

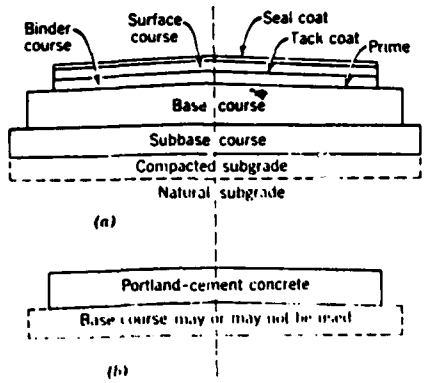


Figure 8.1
(Source 4.-5)

The strength of the flexible pavement (which includes all the layers from the subbase and above) is derived by building up the layers and distributing the load over the subgrade. The thickness of the pavement will depend on the strength of the subgrade. Generally, the higher the subgrade strength, the less pavement thickness is needed.

Figure 8.1b illustrates the different components of a typical rigid pavement. Concrete has a high rigidity and modulus of elasticity, thus the traffic load is spread out over a wide area. A major portion of the structural capacity is carried by the slab itself, thus the subgrade strength is not as important.

The many factors which need to be examined when designing for a particular strength include:

- Load and traffic analysis .
- Environmental factors.

- Stress-strain analysis.

- Material properties of each of the layers and the subgrade material.

In addition, a cost analysis is usually performed to determine the most economical solution to meet the needs of the people. The major emphasis of this chapter examines the different factors influencing pavement design thickness and several different major methods used for designing only the thickness of pavements.

8.2 Factors That Effect Pavement Design

A pavement properly designed and constructed should maintain its designed contour and resist ravelling, break-up, rutting, and potholing. It should also be designed to fulfill its functional usage. It is difficult to determine qualitatively when a pavement has failed functionally, but most methods use the Present Serviceability Index as discussed previously. Traffic considerations are very important to determine the loading and repetitions the pavement will encounter over its lifetime. Most pavement highway design methods use a standard 18 KIP single axle load and can determine other loads as equivalent 18 KIP single axle loads. Whether fixed traffic or fixed vehicle traffic effect are considered, the pavement design thickness decreases as the subgrade strength increases, and the design thickness increases as single wheel loads or repetitions to failure increase.

The main environmental factors to be considered in

pavement design are precipitation and frost conditions. Precipitation is not as important, but seasonal periods of heavy precipitation can affect the moisture content of the subgrade which lowers the strength. It also contributes to frost action. The effects of frost heave can completely destroy a road if not accomodated in the initial design. Ice crystals are formed in frost susceptible courses which can raise a portion of pavement. Strength is also lost during the frost-melt period.[46]

Frost action is minimized by keeping the subgrade dry by using good materials and drainage and low moisture conditions. Flexible pavements need a base thickness such that the vertical compressive subgrade stress or deflection is less than the designed allowable stress. The flexible pavement is built in layers, with each layer having successively larger modulus values in the upper layers. The load spreading capabilities are obtained mostly from the thickness of the granular base and subbase layers. As the stiffness of the upper layers increase, the subgrade deflection is decreased and the pavement acts more like a rigid pavement.

Economic factors always are incorporated in design work. If money was no object, secondary roads could be constructed the same as an expressway. But in reality, tax dollars usually pay for roads, so the best pavement for the money is usually chosen. A variety of feasibility studies can be used be used to determine the most economical design.

8.3 Flexible Pavement Design Methods

8.3.1 The AASHTO Interim Guide Method. The AASHTO flexible pavement design method is based on the AASHTO Road Test which determined a road user type definition of pavement failure, rather than a structural failure. The test demonstrated the major influence of traffic loads and repetitions on design thickness. This method of design incorporates six factors:

1) Traffic information.
2) Serviceability at the end of design life.
3) Environmental conditions.
4) Properties of paving materials.
5) Properties of subgrade materials.
6) Construction and maintenance conditions.

Equivalent axle loads (EAL) are used to quantify the number of repetitions and how heavy the axle loads are over the service life of the pavement. An average daily equivalent axle load is commonly used over a ten year design life for flexible pavements and a twenty year design life for rigid pavements. The terminal serviceability is the lowest serviceability to be tolerated on a road at the end of its life. A regional factor (R) is used to take into account climate conditions. Table 8.1 shows the regional factor values for usual design conditions.

Regional Factors

CONDITION	(R) VALUE
ROADBED MATERIALS FROM 5" DEPTH OR MORE	0.2 - 1.0
ROADBED MATERIALS DRY, SUMMER & FALL	0.3 - 1.5
ROADBED MATERIALS WET, SPRING THAW	4.0 - 5.0

Table 8.1
(Source 4.-510)

A Structural Number (SN) representing the structurablilty of the pavement materials derived from traffic analysis, soil conditions, and a regional factor. It can be converted to a thickness of different structural layers by:

$$SN = a_1 D + a_2 D + a_3 D$$

The (a) values are coefficients for each layer, which correlates the ability for each material in a layer to act as a structural component of the pavement. Table 8.2 shows typical AASHTO values for (a).

A required structural number of a pavement can be determined by the use of a nomograph which relates design parameters for a specific terminable serviceability.

A soil support value (S) reflects the properties of the subgrade and measures the structurability of the soil.

Lastly, minimum layer thicknesses are used and based primarily upon construction and maintenance considerations. Minimum thickness suggested are 2, 4, and 6 inches for the surface, base, and subbase courses respectively.

The thickness values (D) for each layer can be solved

for also by using a nomograph which correlate the coefficient (a) and various other parameters depending on which agency developed the graph.[48]

Structural Layer Coefficients (a) Values

Surface course	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44
Sand asphalt	0.40
Base course	
Sandy gravel	0.07
Crushed stone	0.14
Cement-treated (no soil-cement)	
Compressive strength @ 7 days	
650 psi or more[d]	0.23
400 psi to 650 psi	0.20
400 psi or less	0.15
Bituminous-treated	
Coarse-graded	0.34
Sand asphalt	0.30
Lime-treated	0.15-0.30
Subbase course	
Sandy gravel	0.11
Sand or sandy clay	0.05-0.10

Table 8.2
(Source 4.-512)

8.3.2 The Multilayer Elastic Analysis method is based upon limiting strains in the asphalt surface and permanent deformation in the subgrade. The method involves the consideration of three factors:

1) The theory used.

2) Material consideration value.

3) Development of failure criterion for each mode of distress.

The method considers both permanent deformation as well as

mode of distress.

The method considers both permanent deformation as well as fatigue cracking of the asphalt-bound layer as the most significant failure mechanisms. Results for this design method will vary depending on which loading criteria is used with the multilayered elastic theory. A standard criteria is the Kentucky Method which is based upon a 9-KIP single (circular) load with a tire pressure of 80 PSI. This traffic loading can be converted to AASHTO(EAL) or 18 KIP axle loads.

The elastic theory uses the relationship between the ratio of the vertical subgrade strain at the given wheel load versus the standard load. An allowable strain value can be determined for a specific number of 18 KIP axle load repetitions. The development of the limiting tensile strain criteria for fatigue cracking was based upon an analysis of existing fatigue results coupled with a control section. Design thicknesses are determined with the use of developed nomographs. Nomographs are constructed for percent asphalt-concrete design thickness[49]

8.3.3 <u>The Asphalt Institute Design</u> method is the only method that obtains the design thickness based upon pavement comprised entirely of asphaltic mixtures. The design thickness, expressed in terms of the full-depth asphalt pavement (Ta), is based upon the analysis of asphalt pavement performance, which is based on the AASHTO road test. It is a function of the critical subgrade strength, anticipated 18-KIP applications to reach a terminal

serviceability of 2.5, and the relative strength of component layers comprising the pavement.

This method uses substitution ratios suggested for:

a) hot-mix sand asphalt bases (1.3:1)

b) liquid emulsified asphalt bases (1.4:1)

c) untreated granular bases (2:1)

d) untreated granular subbases (2.7:1)

The ratios allow for alternate pavement designs to be obtained. The basic thickness relationship between thickness, load, and repetitions were developed by using AASHO test loops and incorporate a factor to handle mixed traffic effects. The basis for handling mixed traffic effects are by using equivalent damage factors based upon equal performance.

This design method also correlates CBR values to T_{a50} to incorporate the effect of variable subgrade support.

8.3.4 <u>The National Crushed Stone Association Design</u> is based upon the U.S. Corps of Engineers CBR method of pavement design. The method provides for adequate thickness and quality of material to prevent repetitive shear deformations within any layer. Frost action effects are incorporated and minimized.

The traffic parameter is defined by using the Design Index (DI) or the use of AASHTO equivalencies. Table 8.3 shows approximate values for DI and EAL (18-KIP axle loads).

Design Index Catagories For Traffic

Design Index	General Character	Daily EAL
DI-1	Light traffic (few vehicles heavier than passenger cars, no regular use by Group 2 or 3 vehicles)	5 or less
DI-2	Medium-light traffic (similar to DI-1, maximum 1000 VPD, including not over 5% Group 2, no regular use by Group 3 vehicles)	6-20
DI-3	Medium traffic (maximum 3000 VPD, including not over 10% Group 2 and 3, 1% Group 3 vehicles)	21-75
DI-4	Medium-heavy traffic (maximum 6000 VPD, including not over 15% Group 2 and 3, 1% Group 3 vehicles)	76-250
DI-5	Heavy traffic (maximum 6000 VPD, may include 25% Group 2 and 3, 10% Group 3 vehicles)	251-900
DI-6	Very heavy traffic (over 6000 VPD, may include over 25% Group 2 or 3 vehicles)	901-3000

Table 8.3
(Source 4.-537)

The subgrade strength properties are incorporated in the design method by using the CBR test procedures. If all three factors are present for frost action (water source, slowly depressed air temperatures, and frost susceptible soils), then the design thickness is checked for adequacy during the adverse conditions of the freeze-thaw cycle. Frost protection is most important were F-4 soils are encountered. The Army Corps of Engineers F-4 soils as the most frost susceptable. The final design thickness is then the maximum of the basic CBR structural design reduced by a factor for frost protection. In addition, proper compaction with depth of the structure will limit densification under traffic. This factor is also incorporated when using this method.[51]

8.3.5 The California Method of Design is based upon designated stabilometer values (R) and gravel equivalents of structural layers in feet as shown in figure 8.4. Swell pressures of expansive soils are also taken into account when designing the pavement.

The Traffic Index (TI) is used for traffic information which is easily computed from Equivalent Wheel Loads (EWL)

The design equation is based on field performance surveys:

$$GE = 0.0032(TI) \times (100 - R)$$

GE = Gravel Equivalent

TI = Traffic Index

R = Stabilometer Value

Once the Gravel Equivalent factors are determined for each surface, base, and subbase courses, the design thickness for each course is determined using developed nomographs.[52]

8.4 Rigid Pavement Design Methods

8.4.1 The Portland-Cement Association Method is based upon the number of repeated loads and their magnitudes, modulus of rupture of the concrete, and the subgrade reaction. As a rule, designs are based upon the concrete modulus of rupture that is 110% of the 28 day strength. As hinted before, the thickness of the concrete pavement is relatively insensitive to the modulus of the subgrade support, but a difference can be found when comparing very poor subgrades to very strong subgrades.

A stress ratio is used to account for the fatigue of

CALIFORNIA GRAVEL EQUIVALENTS OF STRUCTURAL LAYERS IN FEET

Actual Thickness of Layer	ASPHALT CONCRETE Traffic Index (TI) 5 and below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	Cement-treated Base BTB and LTB	Class A	Class B	Aggregate Base	Aggregate Sub-base
	Gravel Equivalent Factor (G_f)										G_f	G_f		G_f	G_f
(ft)	2.50	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.2	1.7	1.2	1.1	1.0
0.10	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.12				
0.15	0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.18				
0.20	0.50	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.24				
0.25	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.30				
0.30	0.75	0.70	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.46	0.36				
0.35	0.88	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.42			0.39	0.35
0.40	1.00	0.93	0.86	0.80	0.76	0.72	0.68	0.66	0.63	0.61	0.48			0.44	0.40
0.45		1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.54	0.77	0.54	0.50	0.45
0.50		1.16	1.07	1.01	0.95	0.90	0.86	0.82	0.79	0.76	0.60	0.85	0.60	0.55	0.50
0.55			1.18	1.11	1.04	0.98	0.94	0.90	0.86	0.84	0.66	0.94	0.66	0.61	0.55
0.60				1.21	1.13	1.07	1.03	0.98	0.94	0.91	0.72	1.02	0.72	0.66	0.60
0.65				1.31	1.23	1.16	1.11	1.07	1.02	0.99	0.78	1.11	0.78	0.72	0.65
0.70					1.32	1.25	1.20	1.15	1.10	1.06	0.84	1.19	0.84	0.77	0.70
0.75						1.34	1.28	1.23	1.18	1.14	0.90	1.28	0.90	0.83	0.75
0.80						1.43	1.37	1.31	1.26	1.22	0.96	1.36	0.96	0.88	0.80
0.85						1.52	1.45	1.39	1.33	1.29	1.02	1.45	1.02	0.94	0.85
0.90							1.54	1.48	1.41	1.37	1.08	1.53	1.08	0.99	0.90
0.95								1.56	1.49	1.44	1.14	1.62	1.14	1.05	0.95
1.00								1.64	1.57	1.52	1.20	1.70	1.20	1.10	1.00
1.05									1.65	1.60	1.26	1.79	1.26	1.16	1.05

Note:

BTB is bituminous treated base

LTB is lime treated base

For the design of road mixed asphalt surfacing, use 0.8 of the gravel equivalent factors (G_f) shown above for the asphalt concrete

Figure 8.4
(Source 4.-541)

the concrete pavement. It is the ratio of flexural stress to the modulus of rupture. Fatigue failure occurs when a material ruptures under continued repetitions of loads that cause stress ratios of less than one. Fatigue research has shown that the number of stress repetitions without loss in load bearing capacity, is nearly unlimited. To be conservative, the design ratio is reduced to .50. Load safety factors are used. Table 8.4 shows recommended load safety factors:

Load Safety Factors

Condition	Load Safety Factor
Heavy Truck Traffic	1.2
Moderate Truck Traffic	1.1
Small Volume Truck Traffic	1.0

Table 8.4
(Source 4.-601)

For design purposes, the traffic is categorized into axle-load groups and the stress for an assumed depth of pavement is found by using developed nomographs. Allowable repetitions of each load is determined and the percentages are summed. If the total percentage is less than 100%, then the design is good.[53]

8.4.2 The AASHTO Interim Guide method of design for rigid pavements takes different factors into account than for the flexible pavement design. Design thickness can be very easily found by the use of a developed nomograph.

The following factors are accounted for in the nomograph:

- Modulus of the subgrade.

- Working stress of concrete, taken as 75% of the modulus of rupture.

- Total daily equivalent 18-kip single-axle load applications.[54]

8.5 Concrete Pavement Joints and Reinforcement

In addition to thickness design for concrete pavements, Joints and reinforcement are designed. This section discusses the different joints and reinforcements and the reasons for them.

Longitudinal Joints - Longitudinal joints are used to tie two lanes together and to control longitudinal cracking. Tongue and groove construction can be used when lanes are constructed separately, but sawed joints are frequently used. Tie bars or connectors are used to hold the lanes together.

Expansion Joints - Expansion joints prevent the development of compressive stresses from volume changes. Also, they prevent excessive pressures from being transferred to adjacent structures. When expansion joints are used, dowel bars should also be used to aid in load transfer.

Contraction Joints - Contraction joints provide a predetermined location and arrangement for cracking that will occur. When joints are spaced properly, minimum cracking will occur elsewhere. Skewed joints help to improve load transfer, but dowel bars should be used unless

the slabs are spaced 15 feet or shorter.

Transverse Joints - Transverse joints are sometimes desired to prevent longitudinal warping. They are similar to longitudinal joints and can be placed at intervals between contraction joints.[55]

CHAPTER 9
SUMMARY AND CONCLUSIONS

The cost of building and maintaining roads in a safe and usable condition for the public can vary greatly. The most important point a pavement manager should consider is that one of the functions of pavement management is to provide and maintain roads so that they are economical, thus ways to reduce cost should be examined for every factor of pavement management.

The largest cost factor in pavement management may be management practices themselves. PMSs are becoming more and more popular and reliable for even small municipalities. Many agencies still repair or rebuild pavements as they fail or when funds become available. Usually no long range program is in place to protect the large capitol investment of the road network. A proper program or PMS installed can aid in budget justification and to effectively manage the road system, which will save money in the long run.

Careful analyzation of the different design strategies is a must. All factors need to be examined. Historical records yield valuable information which can be used in the development of strategy. The advantages and disadvantages of the method which is used for optimizing benefits, need to be understood so the pavement manager can make the best decision. Deferred maintenance costs should influence greatly the selection of projects.

Quality management is very important. Both quality assurance in the design procedures and quality control in

the construction phase will save money and limit the amount of rework and the inconvenience of early repairs.

Coordination between agencies and activities can improve efficiency of operations and reduce costs. Equipment sharing can be mutually beneficial as can buying bulk materials to receive discounts. Technology, ideas, and management practices can also be shared to the benefit of the involved parties. Utility projects should always be coordinated with pavement projects to save both money and the inconvenience of two separate projects. Sometimes nothing can be as frustrating to a pavement manager as to complete a project and to have the pavement torn up to install or repair utilities.

Recycling asphalt pavement is becoming more popular and agencies benefit from tremendous cost savings. As the cost of asphalt rises, the savings will be greater. Concrete pavement is also recycled, but basically consists of crushing the pavement and using it as aggregate. An agency can institute a materials reuse program. An area can be set aside to stockpile reuseable construction materials.

There are many ways to cut program costs and the pavement manager should constantly review policy, practices, and new techniques to search for cost savings ideas. Each dollar saved in efficiency can be used in the maintenance of pavements, which can limit the effect of deferred maintenance costs.

If traffic interruptions and money were no problem, pavement management would not be nearly as important as it

is. The facts are that competition for limited tax and legislative funds is intense and will continue to be in the future, and the public just does not like the inconveniences of traffic interruptions and delays. The emphasis in today's highway programs is changing from expansion of the system to preservation and rehabilitation of the current system. There is a marked absence of factual information on the consequences of previous management decisions. A good pavement management program will retain historical data which could be used for future decisions. A learning curve is developed and easily passed on to the next generation because it is well documented. Today's pavement managers need a good program to plan for tomorrow's needs

APPENDIX A
REFERENCES

1. Bateman, John H., Highway Engineering, John Wiley and Sons, Inc., New York, 1939, pp. 2-3.

2. Ibid.

3. Urquhart, Leonard Church, Civil Engineering Handbook, McGraw-Hill Book Company, New York, 1962, p. 2-46.

4. Yoder, E. J. and Witczak, Principles of Pavement Design, John Wiley and Sons, Inc., [illegible]

5. American Association of State Highway and Transportation Officials, AASHTO Guide for Design of Pavement Structures, Volume 2, Ma[illegible] 1985, pp. BB-[illegible] - BB-8.

6. Ibid.

7. National Coordinated Highway Research Program, Report No. [illegible], Running Costs of Motor Vehicles as Affected by Road Design and Traffic, [illegible]

8. AASHTO [illegible]

9. [illegible]

10. Ibid.

11. [illegible] Management Systems [illegible]

12. [illegible]

13. [illegible]

14. [illegible] Pavement Management [illegible]

15. [illegible]

16. [illegible]

19. State of Florida Department of Transportation, Instructions and Procedures For the Flexible Pavement Condition Survey, July 1983.

20. State of Florida Department of Transportation, Instructions and Procedures For the Rigid Pavement Condition Survey, July 1983.

21. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, pp. 8-1 - 8-20.

22. Ibid.

23. Hass, op. cit., pp. 86-95.

24. Ibid.

25. Ibid.

26. Yoder, op. cit., pp. 670-671.

27. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, p. 7-9.

28. Hass, op. cit., pp. 109-111.

29. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, pp. 6-1 - 6-6.

30. Pell, Peter S., Development in Highway Engineering-2, Applied Science Publisher LTD, London, 1978, pp. 115-118.

31. Ibid. pp. 146-150.

32. Ibid.

33. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, pp. 9-1 - 9-3.

34. Hass, op. cit., pp. 200-202.

35. Collier, Courtland A. and Ledbetter, William B., Engineering Cost Analysis, Harper & Row, Publishers, New York, 1982. pp. 152-153.

36. Ibid. p. 119.

37. Ibid. p. 275.

38. Hass, op. cit., pp. 208-216.

39. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, pp. 10-6 - 10-8.

40. APWA, The Hole Story, Facts and Fallacies of Potholes, 1983.

41. U.S. Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, p. I-6.

42. AASHTO, op. cit., p. BB-5.

43. Novak, Robert L., "Managing and Maintaining Pavement", APWA Reporter, December 1983, p. 19.

44. Ibid.

45. Ibid.

46. Yoder, op. cit., pp. 177-186.

47. Ibid. pp. 507-514.

48. Ibid. pp. 519-528.

49. Ibid. pp. 529-535.

[illegible] Ibid. pp. 536-539.

[illegible] Ibid. pp. 540-541.

[illegible] Ibid. pp. 602-603.

[illegible] Department of Transportation, Road Surface Management For Local Governments, Resource Notebook, May 1985, p. 3-9.

[illegible] op. cit. pp. 609-612.

APPENDIX B
SUPPLEMENTAL BIBLIOGRAPHY

Barrish, Raymond A., "Longer Life For Roadways", APWA Reporter, September 1982.

Byrd, Lloyd G. and McMullen, Clifford C., "Life-cycle Costing in Selecting Maintenance Strategies", APWA Reporter, February 1984.

Carriere, Blaise M., "Financing Street Improvements", APWA Reporter, January 1982.

Christman, Robert, "Pavement Management", APWA Reporter, April 1985.

Gillespie, Thomas D. and Sayers, Michael, Measuring Road Roughness and Its Effects on User Cost and Comfort, ASTM, 1985.

McCarty, James E., "Managing Your Pavement Investment", APWA Reporter, December 1982.

Organization For Economic Co-operation and Davelopment,Road Research Group, Use of Waste Materials and By-Products In Road Construction, September 1977.

Salmon, Mike, "PAVER Saves a Million Dollars", APWA Reporter, December 1985.

Shilstone, James F. Sr., "Managing Quality In Construction", APWA Reporter, March 1986.

Transportation Reasearch Board, National Reasearch Council, Maintenance Management Systems, October 1984.

Troyan, Vitaly B., "Computer-scheduled Pavement Repair",APWA Reporter, October 1985.

U.S. Department of Transportation, A User's Manual for A Management Control System for Street Maintenance, June 1978

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